Gold Electroplating Optimization in Diffusion-Limited Regime

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Abstract

High gold electroplating rate was found to have negative impact on through-wafer via step coverage. When the plating rate increased from 2.28 to 3.15 ASF, step coverage decreased by 10%. As part of a process optimization effort, an improved plating recipe that consumed 25% less gold with comparable step coverage was developed.

INTRODUCTION

In gallium arsenide (GaAs) through-wafer via (TWV) metallization process[1], gold is electroplated on the backside of the wafer to form electrical connection to front side devices as shown schematically in Fig. 1. Plating in via is diffusion limited as evidenced by thinner plating. As gold ions are consumed at the electrode or wafer surface during plating, a region depleted of gold ions forms. For plating to continue, additional gold ions from the bulk solution need to diffuse across this depletion layer before reaching the wafer surface. Plating in via is thinner since ions from the bulk solution have to diffuse an extra distance to the bottom of via. This issue becomes even more challenging as vias get smaller.

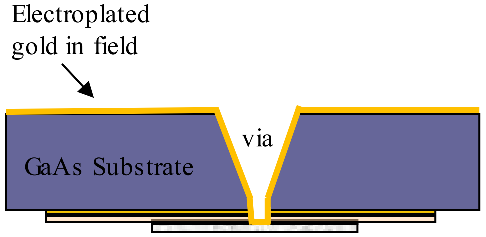


Fig. 1. Schematic cross-section of GaAs wafer with electroplated gold in through-wafer via.

Efforts have been made to improve gold ion diffusion, mainly by increasing bath agitation at the plating surface. This mechanical process creates turbulence in the fluid which improves mixing and increases the interfacial areas where diffusion takes place[2]. A common plating setup is to continuously circulate the plating solution to the wafer while rotating the wafer during plating. Riege et al.[3] reported that a plating anode with circulation holes could also improve the flow dynamics between the anode and the wafer. Circular holes in a cross-pattern provided better plating uniformity and improved plating coverage inside via compared to using anodes without holes.

In this paper, we detail our continued effort to further optimize the TWV gold electroplating in via where deposition is diffusion limited. Comparable via step coverage was achieved with 25% less gold plating.

METHODOLOGY

All plating experiments were carried out on a Semitool Equinox Plating System. Plating rates were varied from 2.1 to 3.15 Amps per Square Foot (ASF). Other parameters such as solution re-circulation rate, temperature, and wafer rotation speed were kept constant. Table 1 summarizes plating rates for one-step and two-step plating conditions. In the one-step plating condition, the plating rate was maintained for the duration of the plating process. For the two-step plating condition, the slower plating rate constituted 75% of total plating. The last 25% was plated faster at 3.15 ASF. The intention of plating slower initially was to achieve better step coverage prior to completing the process at higher plating rate. Both one-step and two-step plating conditions have the same total plating amount in amp-minute.

To demonstrate plating optimization, a standard one-step plating process was modified to plate 25% less gold while maintaining comparable via thickness.

All via step coverage measurements were done with the aid of FIB cross-sections. The thickness ratio of gold at bottom of via to the film thickness in the field is defined as the via step coverage.

$$step\ coverage\ \% = \frac{thickness\ at\ bottom\ of\ via}{thickness\ in\ field} * 100$$

TABLE I PLATING RATES FOR ONE AND TWO-STEP PLATING SEQUENCE

One-Step Plating	**Two-Step Plating**	
Plating Rate (ASF)	Initial Plating Rate (ASF)	Final Plating Rate (ASF)
2.28	2.1	3.15
2.45	2.28	3.15
3.15	2.45	3.15

RESULT AND DISCUSSION

A plot of via step coverage as a function of plating rate is shown in Fig. 2. The average step coverage when plated at 2.28 ASF was 25.1%. At the fastest plating rate, 3.15 ASF, average step coverage reduced to 15.5%. Only two wafers were plated at 2.45 ASF with 26 and 39% coverage. A fitted line supports thinner gold in via as plating rate increases. More data is needed to validate coverage at 2.45 ASF.

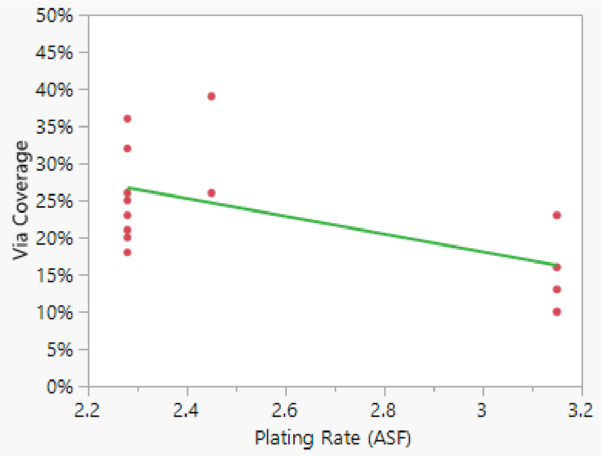


Fig. 2. Via step coverage decreases as a function of plating rate for one-step plating process.

In the two-step plating group, via step coverage also trended with the plating rate. Fig. 3 shows a reduction in step coverage as the initial plating rate increased from 2.1 to 2.28 to 2.45 ASF. The best via step coverage was plated at 2.1 ASF with 28.9%, followed by 2.28 ASF with 27.9%, and then 2.45 ASF with 23.7%. All two-step conditions have the final plating rate at 3.15 ASF. The impact of faster plating in the second step of the two-step plating condition was likely minimal since it only represented 25% of the total plating amount. The limited data suggests comparable if not better step coverage with the two-step 2.1 ASF plating condition than one-step 2.28 ASF plating condition. Future work could explore the balance between slow and fast plating with production output requirements.

The observed reduction in via step coverage at higher plating rate is associated with longer boundary layer. As the rate of gold ions consumption increases at faster plating, the region depleted of gold ions next to the wafer surface also gets wider. Gold ions from the bulk solution need to diffuse across this layer prior to being reduced and plated on the wafer surface. The amount of ions reaching the bottom of via is reduced as this depletion layer increases with plating rate. Gold ions are less likely to diffuse to the bottom of via prior to being consumed at the wafer surface.

To demonstrate TWV via plating optimization, a standard plating condition was made thinner by reducing the total plating amp-minute by 25%. The “Standard” condition was plated at 3.15 ASF while the “Thin” condition was plated at 2.28 ASF. Fig. 4 compares the normalized field thickness between the Standard and the Thin plating conditions.

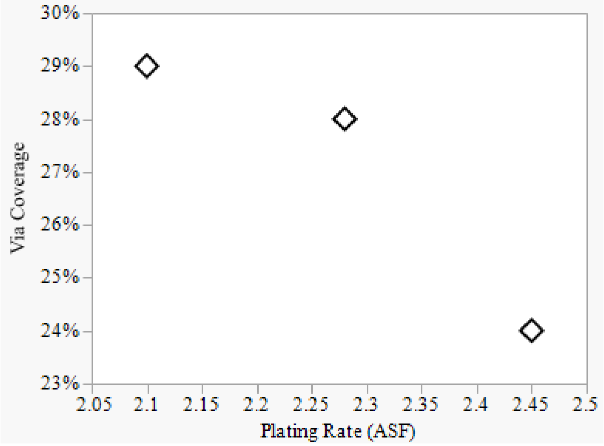


Fig. 3. Via step coverage for two-step plating processes where the initial step was slow and final at 3.15 ASF.

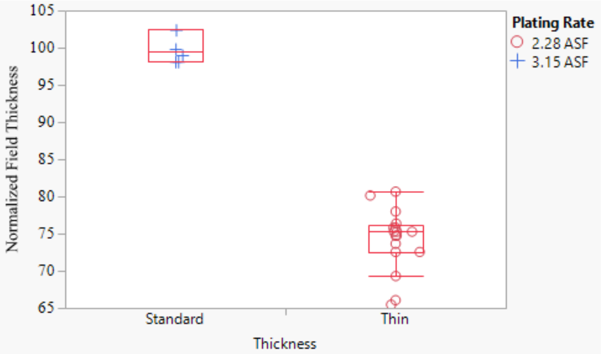
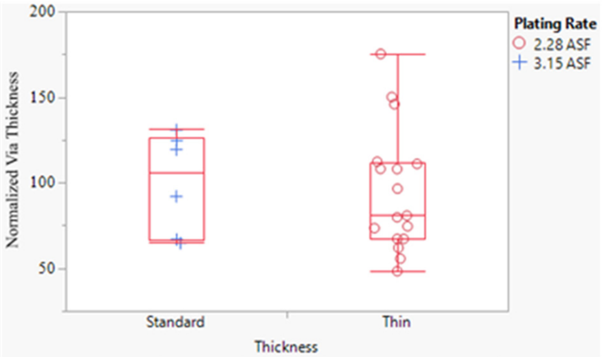


Fig. 4. Thin plating condition is 25% thinner than Standard plating condition.



Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Standard	6	99.9999	29.4100	12.007	69.136	130.86
Thin	17	95.0252	35.9200	8.712	76.557	113.49

Fig. 5. Normalized via thickness showing comparable via thickness between Standard and Thin plating.

Although the field thickness was 25% thinner, the gold thickness in via was only 5% thinner as shown in Fig 5. The Thin condition has slower plating rate which yielded better via step coverage. This made it possible to achieve similar gold thickness in TWV via with 25% less overall gold plating. In addition, the Thin condition has similar plating time as the Standard condition and would not impact manufacturing output negatively.

CONCLUSIONS

When operating in diffusion-limited regime, where the reaction rate is dependent on the speed of reactants reaching the electrode or wafer surface, decreasing the plating rate improves plating step coverage. In TWV metallization process, gold plating is thinner in vias than in the field. The plating rate plays a direct role in via step coverage. As plating rate increases, the step coverage decreases. We demonstrated gold plating process optimization that consumed 25% less gold at slower plating rate. The gold thickness inside vias was comparable to a standard condition which required more gold. The results from this paper are specific to gold plating, but we anticipate the general concepts are applicable to other metal plating chemistries.

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ACRONYMS

ASF: Amps per Square Foot
FIB: Focus Ion Beam
GaAs: Gallium Arsenide
TWV: Through-Wafer Via